

Flavor Physics Landscape a Decade from Now

R. Cahn

P5

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Flavor Physics = Particle Physics

The K meson has been at the heart of most of the advances in particle physics:

- Strangeness
- Mixing of neutral kaons
- $\tau - \theta$ puzzle leads to parity violation
- Strangeness leads to $SU(3)$
- $SU(3)$ leads to quarks
- CP violation in K_L decay
- Absence of neutral weak currents leads to postulate of charm
- ϵ'/ϵ shows direct CP violation

FCNC and CP Violation

- Flavor Changing Neutral Currents suppressed:
 - $\mathcal{B}(K_L \rightarrow \mu^+ \mu^-) = 7 \times 10^{-9}$
 - Standard Model explanation
 - * CKM matrix nearly diagonal
 - * (Most) quark masses small compared to m_W
 - Beyond SM must suppress FCNC too: enormous constraint
- The CP Enigma
 - Why is θ_{QCD} small? why is the EDM of the neutron small?
 - Why is there something rather than nothing?
 - There is more to CP than CKM.

Incompleteness of Standard Model

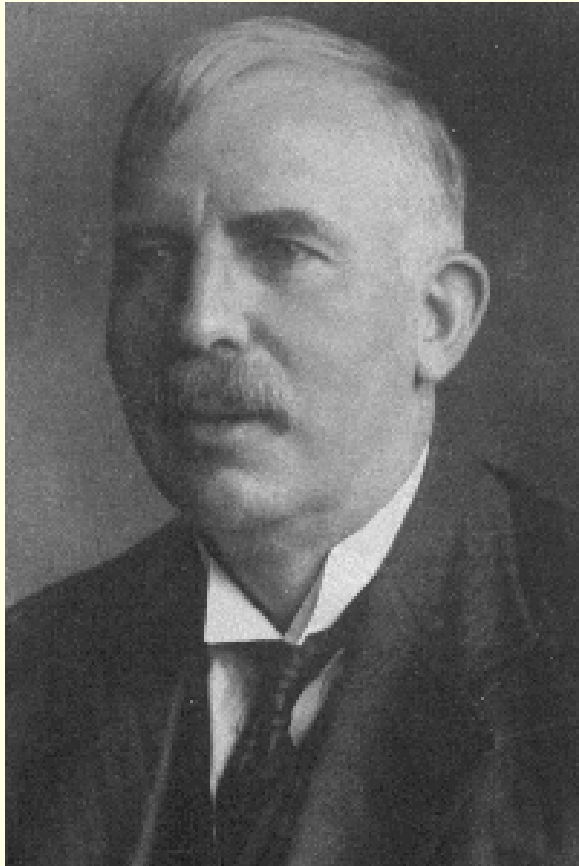
- Electroweak symmetry breaking not understood
- SM explains everything we see, but we don't see most of the stuff in the universe
- Extensions of SM must pass the CP and FCNC tests
- Look for non-SM effects
 - Radiative corrections at Z
 - EDMs
 - Test unitarity triangle
 - * Sides: $b \rightarrow u \ell \nu$, x_s , $K \rightarrow \pi \nu \nu$...
 - * Angles: $B \rightarrow J/\psi K_S$, $B \rightarrow \pi \pi$, etc.
 - * Discrepancies measuring the same thing two ways

History of Virtual Discoveries

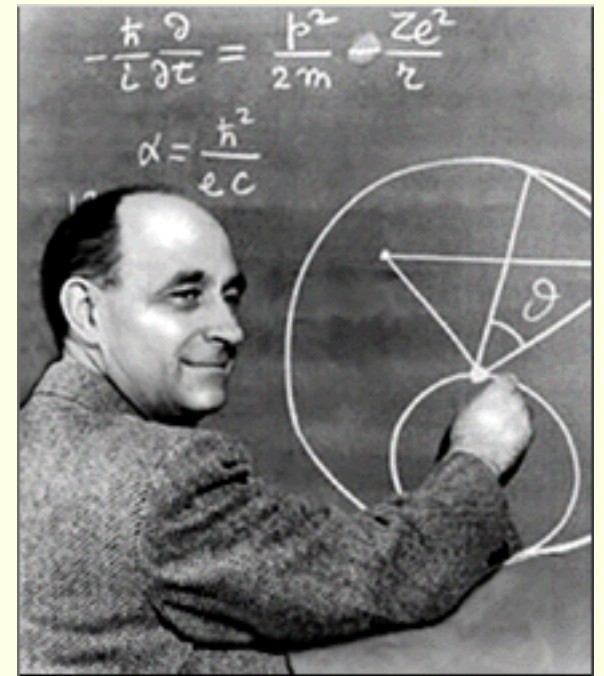
- 1934: Enrico Fermi (or Ernest Rutherford in 1898) discovered the W
- 1973: Gargamelle discovered the Z
- 1974: Ben Lee and Mary K. Gaillard discovered charmed particles
- 1994: LEP discovered the t quark

Predictions of real particles from virtual effects are astonishing.

But few are convincing until the real thing appears.



Who discovered the W boson?



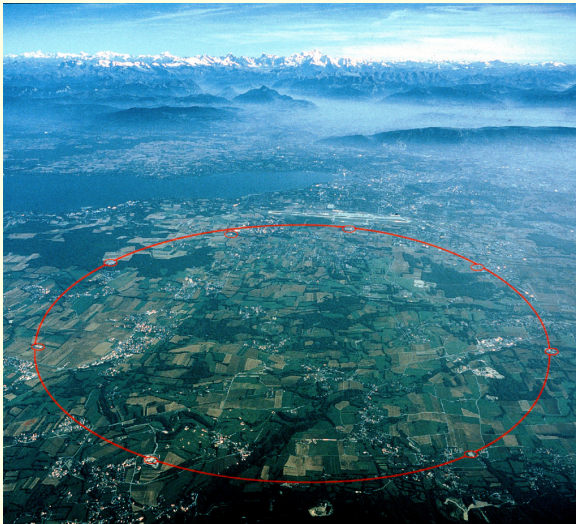
Context for Next Generation Quark Flavor Experiments

- LHC begins ca. 2007, results begin ca. 2008

- Possible scenarios at LHC

- Discovery new spectroscopy:

jackpot for particle physics



- Discover single, orthodox Higgs boson:

happy for 24 hours

- Strongly interacting W , Z (disfavored):

life is tough

- ???

Quark Flavor Physics in LHC Era

- If there is a new spectroscopy:
 - Confirm predicted radiative corrections?
 - Discriminate between possible models?
- If there is an orthodox Higgs
 - Confirm Standard Model predictions
- Something else
 - Confirm (modified?) Standard Model predictions
- A higher standard:
 - With competition from LHC, it will not be enough to find hints of new physics. The demands on precision and clean interpretation will be much greater.

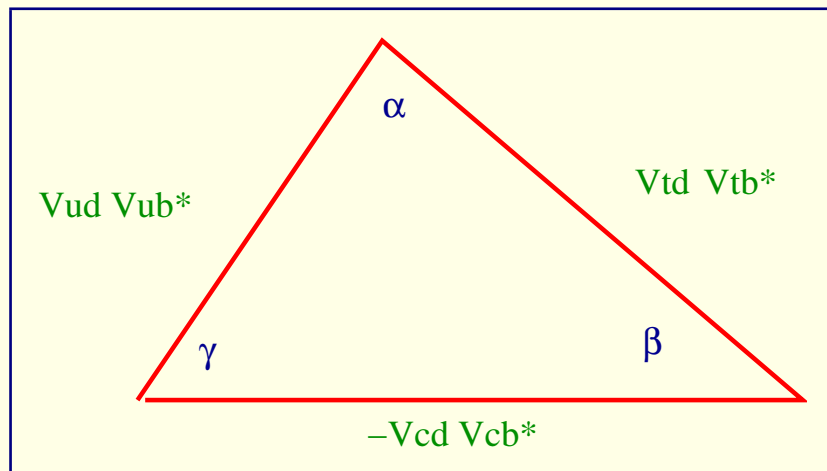
Value of Verifying the Standard Model

- The Standard Model is great!
- LEP/SLC provided magnificent confirmation of part of SM (up to a point)
- Weak-decays are the means to confirm other parts
- This great theory warrants extensive validation
- Already testing loops (mixing, $b \rightarrow s\gamma$)
- QCD is part of the Standard Model, too

CKM and All That

- CKM matrix provides weak phases (1st to 3rd transitions only)

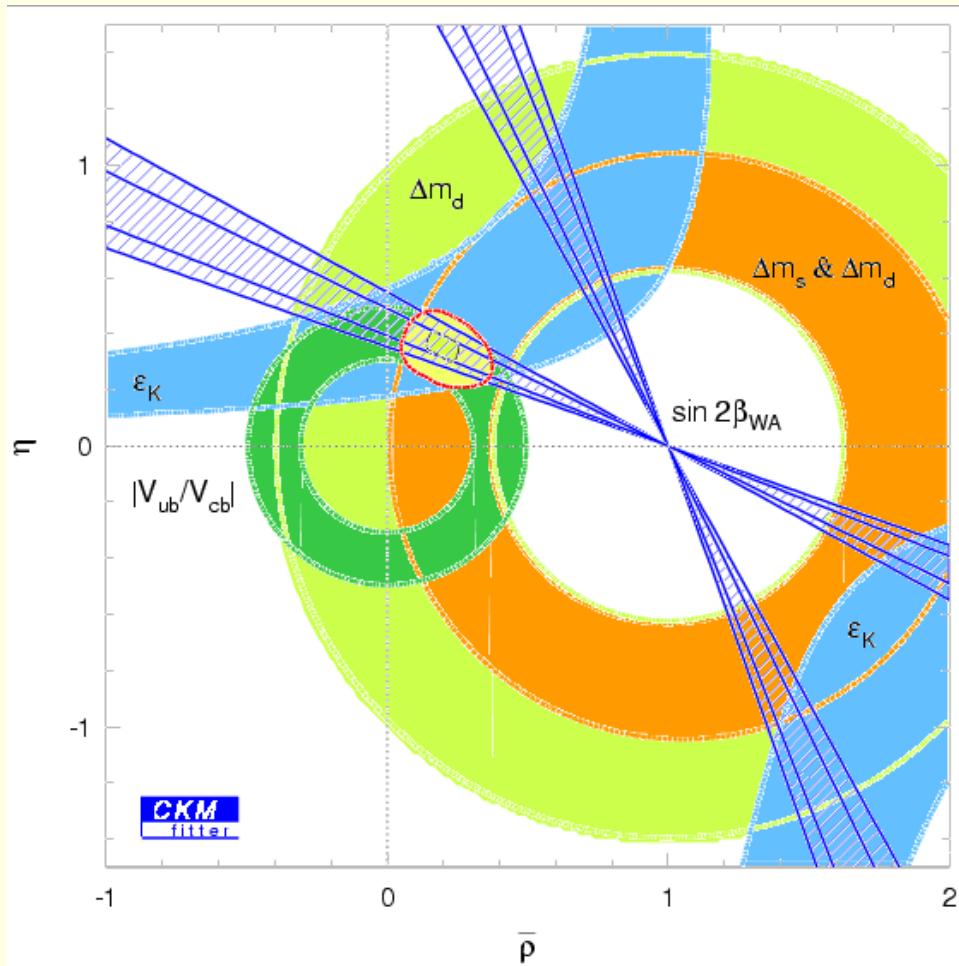
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} = \begin{bmatrix} 1 - \lambda^2/2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & \lambda^2 A \\ \lambda^3 A(1 - \rho - i\eta) & -\lambda^2 A & 1 \end{bmatrix}$$



- Measure $\sin 2\beta$ in $B \rightarrow J/\psi K_S$, etc.
- Measure $\sin 2\alpha$ in $B \rightarrow \pi\pi, \rho\pi$ etc.
- Measure γ in $B \rightarrow DK$, etc.
- Measure V_{ub}, V_{cb}

Wolfenstein representation: $V_{ub} \propto e^{-i\gamma}$, $V_{td} \propto e^{-i\beta}$

Unitarity Triangle Today



- $\epsilon_K = 2.271 \pm 0.017 \times 10^{-3}$
- $|V_{ub}/V_{cb}| = 3.7 \times 10^{-3}/40. \times 10^{-3}$
- $\Delta m_d = 0.503 \pm 0.006 \text{ ps}^{-1}$
- $\Delta m_s > 14.4 \text{ ps}^{-1}$
- $\sin 2\beta = 0.734 \pm 0.054$

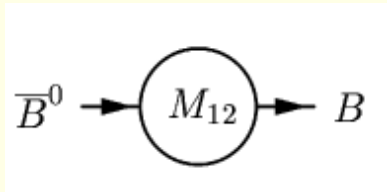
$B^0 - \bar{B}^0$ Mixing Primer

Tagging = identify flavor of other (or same-side) B

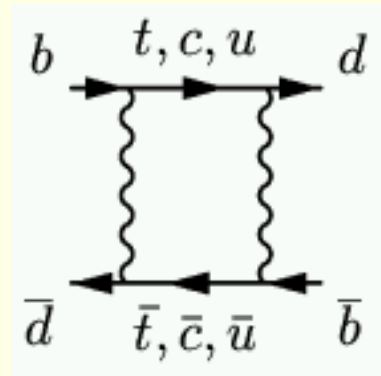
$$|B_{phys}^0(t)\rangle \propto \cos(\Delta mt/2)|B^0\rangle + i\frac{q}{p}\sin(\Delta mt/2)|\bar{B}^0\rangle$$

$$|\bar{B}_{phys}^0(t)\rangle \propto \cos(\Delta mt/2)|\bar{B}^0\rangle + i\frac{p}{q}\sin(\Delta mt/2)|B^0\rangle$$

$$q/p = -\frac{|M_{12}|}{M_{12}} = -\frac{M_{12}^*}{|M_{12}|} \quad A = \langle f|\mathcal{H}|B^0\rangle \quad \bar{A} = \langle f|\mathcal{H}|\bar{B}^0\rangle$$



Standard
Model:



$$\propto e^{2i\beta}$$

$$\lambda = \frac{q}{p} \frac{\bar{A}}{A} : \text{independent of convention}$$

Time-Dependence in Mixing

$$|\langle f | \mathcal{H} | B_{phys}^0(t) \rangle|^2 = |A|^2 \left[\frac{1}{2}(1 + |\lambda|^2) + \frac{1}{2}(1 - |\lambda|^2) \cos \Delta m t - \mathcal{I}m \lambda \sin \Delta m t \right]$$

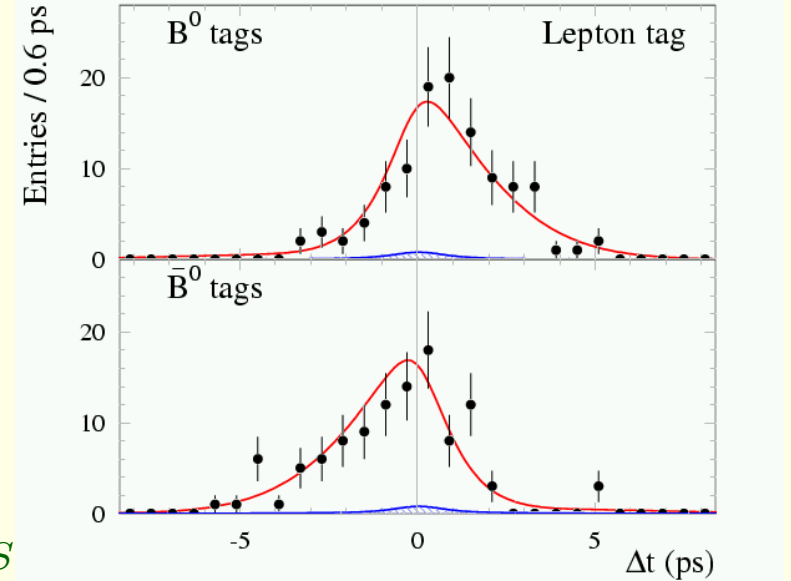
$$|\langle f | \mathcal{H} | \bar{B}_{phys}^0(t) \rangle|^2 = |A|^2 \left[\frac{1}{2}(1 + |\lambda|^2) - \frac{1}{2}(1 - |\lambda|^2) \cos \Delta m t + \mathcal{I}m \lambda \sin \Delta m t \right]$$

When $|f\rangle$ is a CP eigenstate and just one contributing amplitude, $|\lambda| = 1$:

$$|\langle f | \mathcal{H} | B_{phys}^0(t) \rangle|^2 = |A|^2 [1 - \mathcal{I}m \lambda \sin \Delta m t]$$

$$|\langle f | \mathcal{H} | \bar{B}_{phys}^0(t) \rangle|^2 = |A|^2 [1 + \mathcal{I}m \lambda \sin \Delta m t]$$

BaBar lepton-tagged $B \rightarrow J/\psi K_S$



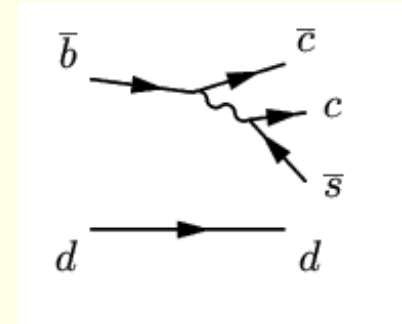
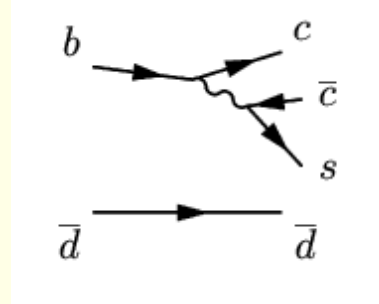
$B \rightarrow J/\psi K_S$

1. Measure: mixing angle ($\arg M_{12}$)

2. Theory problems: none

3. Experimental problems: none

4. Precision in $\sin 2\beta$



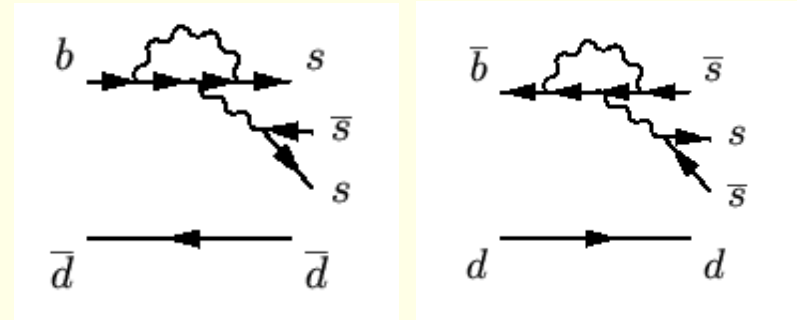
$$\lambda = \frac{q}{p} \frac{\bar{A}}{A} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{cb} V_{cs}^*}{V_{cb}^* V_{cs}} = (-1) e^{-2i\beta}$$

BaBar/Belle		BTeV/LHC-b	Super B
0.1 ab^{-1}	0.5 ab^{-1}	10^7 s	10 ab^{-1}
$0.067 \oplus 0.033$	0.03	0.017	0.008

$$B \rightarrow \phi K_S$$

1. Measure: mixing angle and possible new physics penguin phase

2. Theory motivation: new physics could compete well with loop



$$\lambda = \frac{q \bar{A}}{p A} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{tb} V_{ts}^*}{V_{tb}^* V_{ts}} = (-1) e^{-2i\beta}$$

3. Experimental problems: low branching ratio

4. Precision in $\sin 2\beta$

BaBar/Belle		BTeV/LHC-b	Super B
0.1 ab^{-1}	0.5 ab^{-1}	10^7 s	10 ab^{-1}
$0.51 \oplus 0.09$	0.23	0.14	0.056

$B \rightarrow \pi\pi$

1. Measure: mixing angle ($\arg M_{12}$) plus 2γ , i.e. $2\pi - 2\alpha$

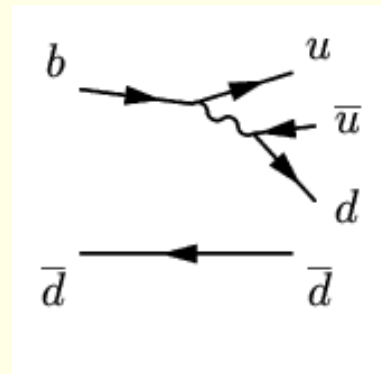
2. Theory concern: prominent penguin contribution

3. Experimental problems: small branching ratio for $\pi^0\pi^0$

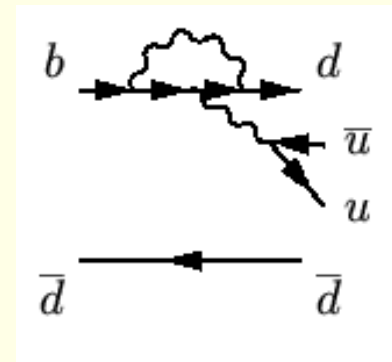
- Penguins are $\Delta I = 1/2$ operators, trees $\Delta I = 3/2, 1/2$

- Use isospin to isolate $I = 2$ final state (no penguin contribution)

Tree



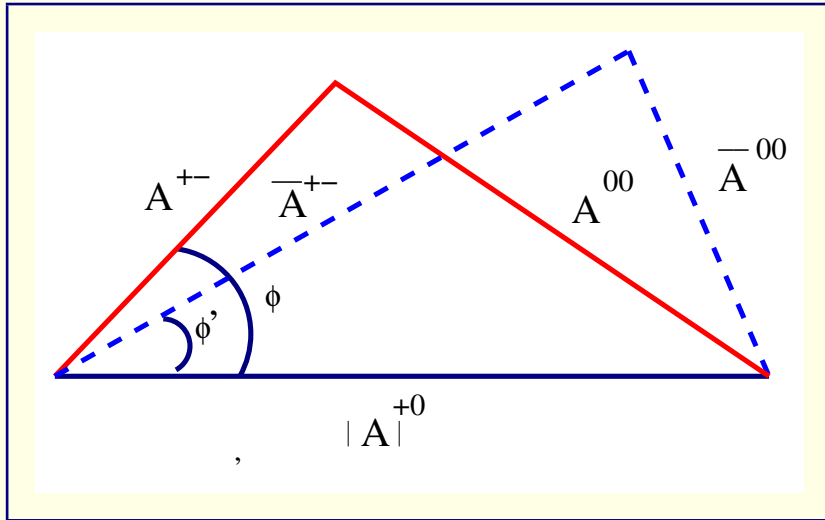
Penguin



$$\lambda_{Tree} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{ub} V_{ud}^*}{V_{ub}^* V_{ud}} = e^{2i\alpha}$$

$$\lambda_{Penguin} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{tb} V_{td}^*}{V_{tb}^* V_{td}} = 1$$

Fighting Penguins in $B \rightarrow \pi\pi$



α_{eff} from time-dependent $B^0, \bar{B}^0 \rightarrow \pi^+ \pi^-$

$$2\alpha = 2\alpha_{eff} + \phi - \phi'$$

(Four-fold) Ambiguity: $\phi \rightarrow -\phi$

- Measure time-integrated $\Gamma(B^+ \rightarrow \pi^+ \pi^0) = \Gamma(B^- \rightarrow \pi^- \pi^0)$
- Separately measure time-integrated $\Gamma(B^0 \rightarrow \pi^0 \pi^0), \Gamma(\bar{B}^0 \rightarrow \pi^0 \pi^0)$

$$\cos \phi = \frac{\mathcal{B}(\pi^+ \pi^0) + \frac{1}{2}\mathcal{B}(\pi^+ \pi^-) - \mathcal{B}(\pi^0 \pi^0)}{\sqrt{2\mathcal{B}(\pi^+ \pi^-)\mathcal{B}(\pi^+ \pi^0)}}$$

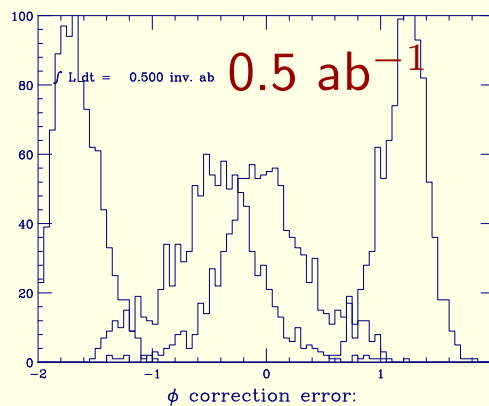
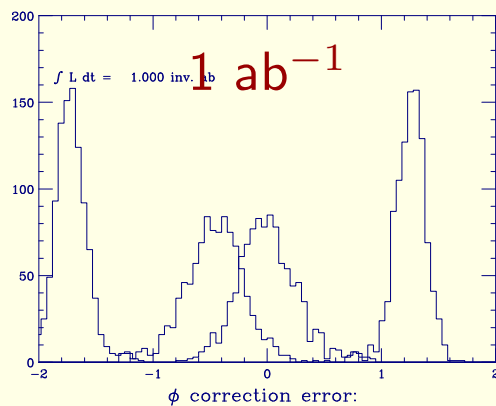
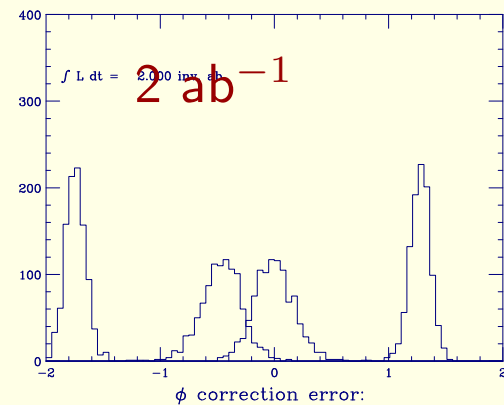
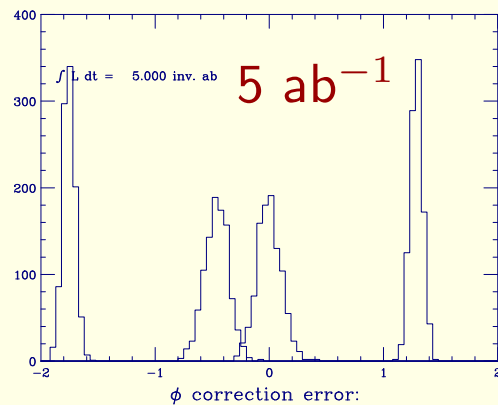
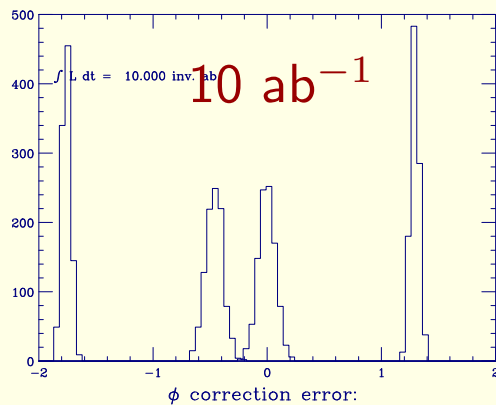
Ambiguities Bite

- Snowmass study says $\sigma(\alpha : \text{BaBar/Belle}) < 18^\circ$, $\sigma(\alpha : \text{SuperB}) < 7^\circ$
- Toy Monte Carlo study (RNC and Roodman):

Branching ratios are in units of 10^{-6} .

Background based on BaBar results

$B^\pm \rightarrow \pi^\pm \pi^0$	4.1
$B^0 \rightarrow \pi^+ \pi^-$	4.7
$\bar{B}^0 \rightarrow \pi^+ \pi^-$	4.7
$B^0 \rightarrow \pi^0 \pi^0$	2.5
$\bar{B}^0 \rightarrow \pi^0 \pi^0$	1.5



- histogram of 1000 experiments, $-2 < \text{error in } 2\alpha_{eff} < 2$
- Precision measurement of α in $\pi\pi$ requires enormous integrated luminosity
- This seems to be a possibility only for a $10^{36} \text{ cm}^{-2} \text{ s}^{-1} e^+e^-$ machine

α from $B \rightarrow \rho\pi$

1. Measure: mixing angle 2β plus 2γ ,
i.e. $2\pi - 2\alpha$

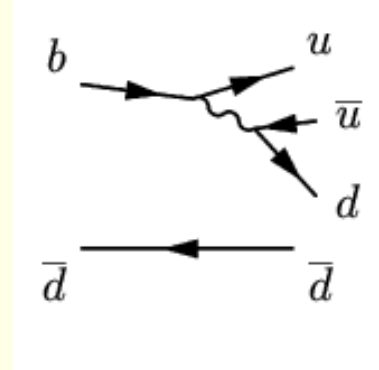
2. Theory is clean

3. Experimental problems: low
branching ratio for $\rho^0\pi^0$,
backgrounds, most information
comes from events with low energy
 π^0

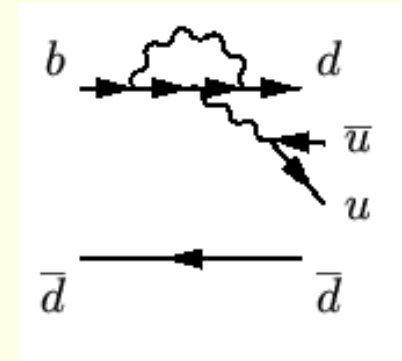
4. BTeV's calorimeter and vertex trigger provide advantages over LHC-b

5. BTeV claims resolution in α of $1.4^\circ - 4.3^\circ$ in 2×10^7 s

Tree



Penguin



$$\lambda_{Tree} = \eta \frac{V_{tb}^* V_{td} V_{ub} V_{ud}^*}{V_{tb} V_{td}^* V_{ub}^* V_{ud}} = e^{2i\alpha}$$

$$\lambda_{Penguin} = \eta \frac{V_{tb}^* V_{td} V_{tb} V_{td}^*}{V_{tb} V_{td}^* V_{tb}^* V_{td}} = 1$$

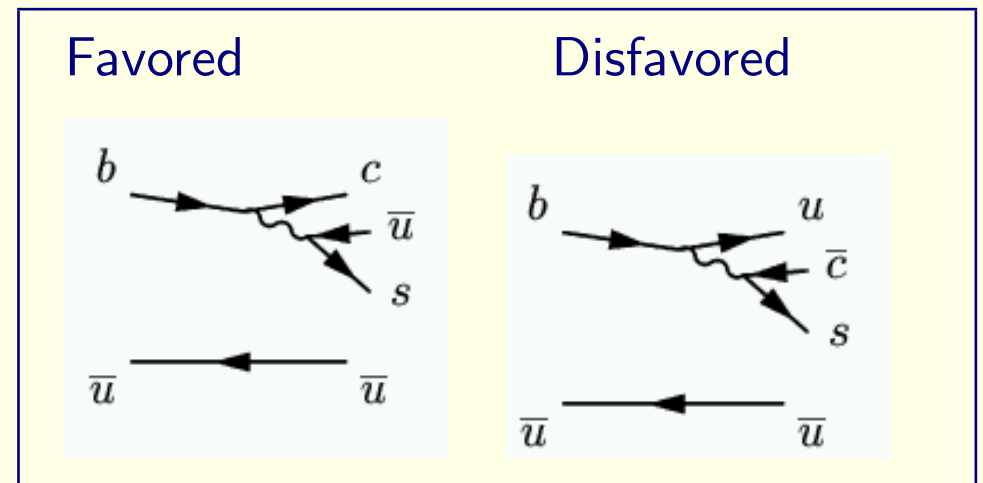
γ from $B \rightarrow DK$

1. Measure: interference between

$$\begin{aligned}
 B^+ &\rightarrow K^+ D^0 \text{ (disfavored)} & D^0 &\rightarrow f_i \text{ (favored)} \quad (i = 1, 2) \\
 B^+ &\rightarrow K^+ \bar{D}^0 \text{ (favored)} & \bar{D}^0 &\rightarrow f_i \text{ (disfavored)} \quad (i = 1, 2)
 \end{aligned}$$

2. Theory motivation: clean, no assumptions about final state interactions, etc.

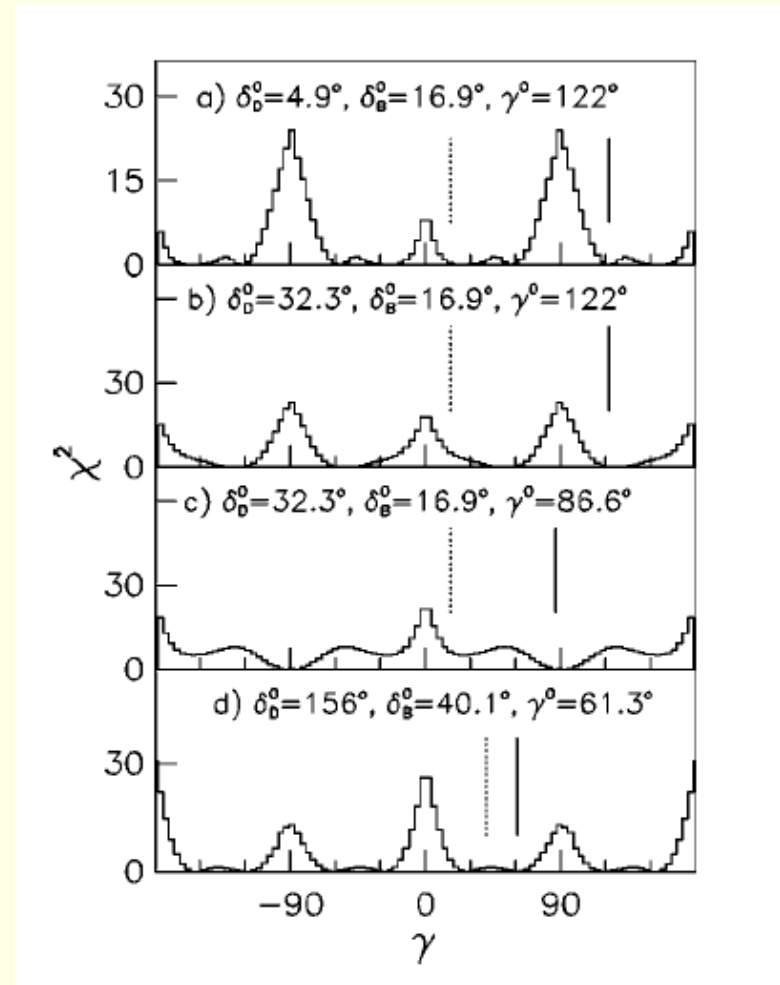
3. Experimental problems: low branching ratios



4. Measure $B^\pm \rightarrow K^\pm f_i$, assume $B^+ \rightarrow K^+ \bar{D}^0$, $D^0, \bar{D}^0 \rightarrow f_i$ known
5. Alternatives: $f = CP$ eigenstate, f singly suppressed

$$\mathcal{B}(B^+ \rightarrow K^+ f_i) = \mathcal{B}(\bar{D}^0 \rightarrow f_i) \mathcal{B}(B^+ \rightarrow K^+ \bar{D}^0) + \mathcal{B}(D^0 \rightarrow f_i) \mathcal{B}(B^+ \rightarrow K^+ D^0) \\ + 2 \cos(\delta_i + \gamma) \sqrt{\mathcal{B}(\bar{D}^0 \rightarrow f_i) \mathcal{B}(B^+ \rightarrow K^+ \bar{D}^0) \mathcal{B}(D^0 \rightarrow f_i) \mathcal{B}(B^+ \rightarrow K^+ D^0)}$$

- Measure four branching ratios, learn disfavored $\mathcal{B}(B^+ \rightarrow K^+ D^0)$, two CP conserving phases, γ
- Study by Abi Soffer using additional D^0 decays to CP eigenstates, too
- With 600 fb^{-1} , hard to exclude large regions of γ
- With 10 ab^{-1} , extrapolate at SuperB γ to $1^\circ - 2.5^\circ$



- Exclusive approach to V_{cb} : $B \rightarrow D\ell\nu$, $B \rightarrow^* \ell\nu$
 - Measure $|V_{cb}| \times \text{form factor}$, known to $\approx 4\%$
- Inclusive approach to V_{cb}
 - Theory under good control: 2%
- Inclusive approach to V_{ub}
 - Make cut in E_ℓ to remove bkgd from $b \rightarrow c\ell\nu$
 - Now theory has uncertainties
 - Could cut on $m_{hadronic} < m_D$
 - Theory still not under control
 - Better to require $q^2 = m_{\ell\nu}^2$ large: fully reconstruct other B
 - May reduce theory uncertainty for $|V_{ub}|$ to 5%
- : Exclusive approach to V_{ub} : lattice calculation of form factors

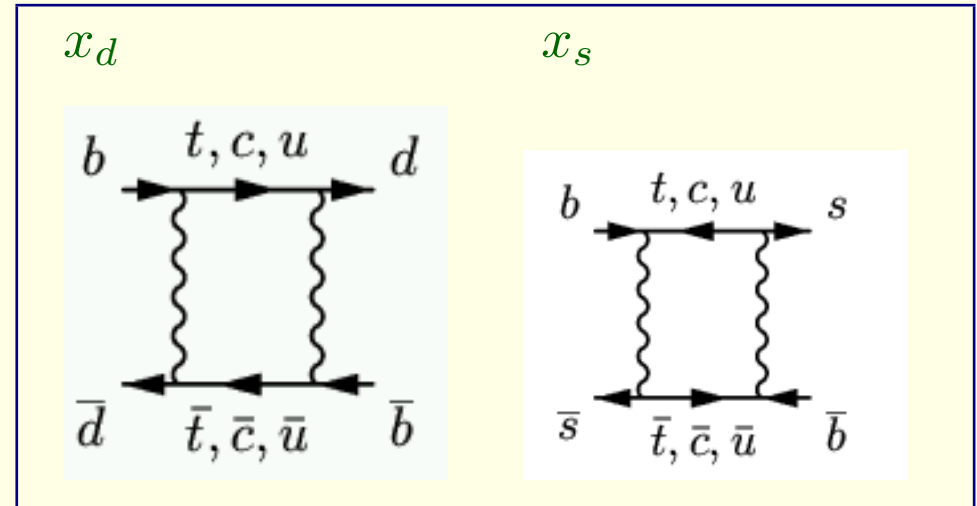
B_s oscillations: x_s

1. Measure: mixing in $B_s - \bar{B}_s$ system

2. Theory issue:

$$x_s/x_d = \frac{m_{B_s} \eta_{B_s} B_{B_s} f_{B_s}^2}{m_{B_d} \eta_{B_d} B_{B_d} f_{B_d}^2} |V_{ts}/V_{td}|^2$$

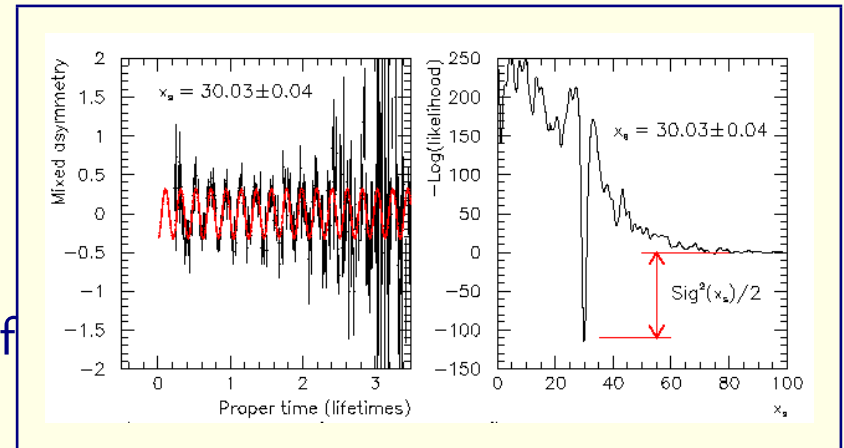
introduces 10% uncertainty in $|V_{td}/V_{td}|$



3. Experimental problems: need B_s !

4. CDF should measure x_s with good precision

5. Lattice calculations needed to get full benefit of BTeV measurement



Hiller-Ligeti Prescription for Happiness

- Tevatron Collider fails to measure Δm_s
- Conclude $\Delta m_s > 60 \text{ ps}^{-1}$
- But then $\Delta\Gamma$ should be large enough to measure

$$\Delta\Gamma/\Delta m = -\frac{3\pi m_b^2}{2 m_t^2} \times (\text{Inami} - \text{Lim}) \times (\text{QCD})$$

- Tevatron fails to find $\Delta\Gamma$
- Conclude there is new physics in $B_s \rightarrow \bar{B}_s$
- Build Linear Collider

Requirement for Precision Test of Unitarity Triangle:

Theory must become as rigorous as experiment.

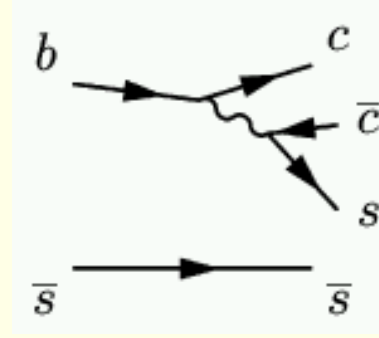
- Theory uncertainties may dominate several key measurements
- Lattice gauge theory especially important
- Established methodology in experiment for statistical and systematic uncertainties
- Without analogous methodology, theory errors not really quantitative

$$B_s \rightarrow J/\psi \phi, J/\psi \eta'$$

1. Measure: analog of $B \rightarrow J/\psi K_S$
No 1st to 3rd, so no asymmetry to lowest order in λ_{CKM}

$$\chi \approx \lambda_{CKM}^2 \eta$$

2. Theory motivation: new physics with phase of $B_d - \bar{B}_d$ mixing would show up



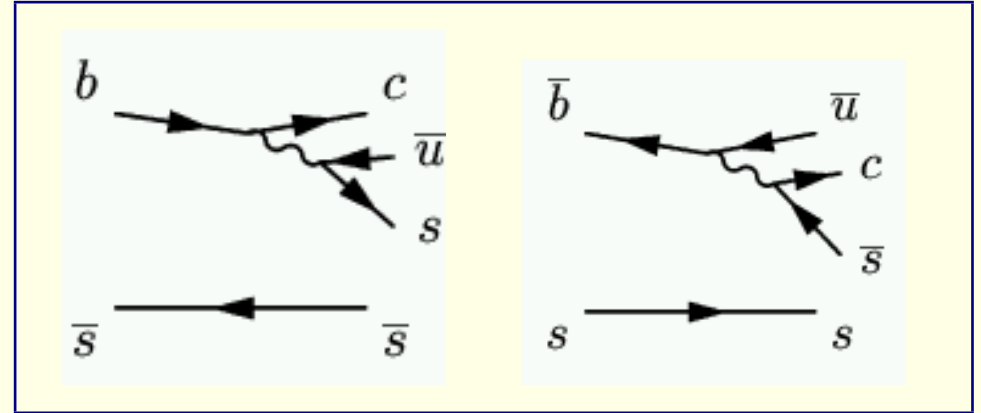
$$\lambda = \frac{q}{p} \frac{\bar{A}}{A} = \eta \frac{V_{tb}^* V_{ts}}{V_{tb} V_{ts}^*} \frac{V_{cb} V_{cs}^*}{V_{cb}^* V_{us}} = 1$$

3. Experimental problems: requires B_s , good spatial resolution

4. BTeV reach in $\sin 2\chi : \pm 0.024$

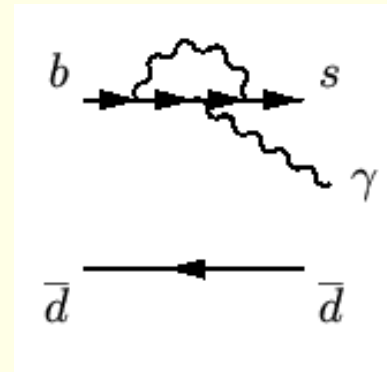
Measuring γ in $B_s \rightarrow D_s^\pm K^\mp$

- Both B_s and \bar{B}_s decay to $D_s^\pm K^\mp$ at same order
- Unlike B_d analog (amplitudes dissimilar sizes)
- True oscillation experiment: B^0 and \bar{B}^0 decay to same state
- BTeV uncertainty estimated at 13°
- Much harder at e^+e^- collider



$$b \rightarrow s \gamma$$

1. Experimental issue: get rid of enormous γ bkgd from π^0 , η , etc.

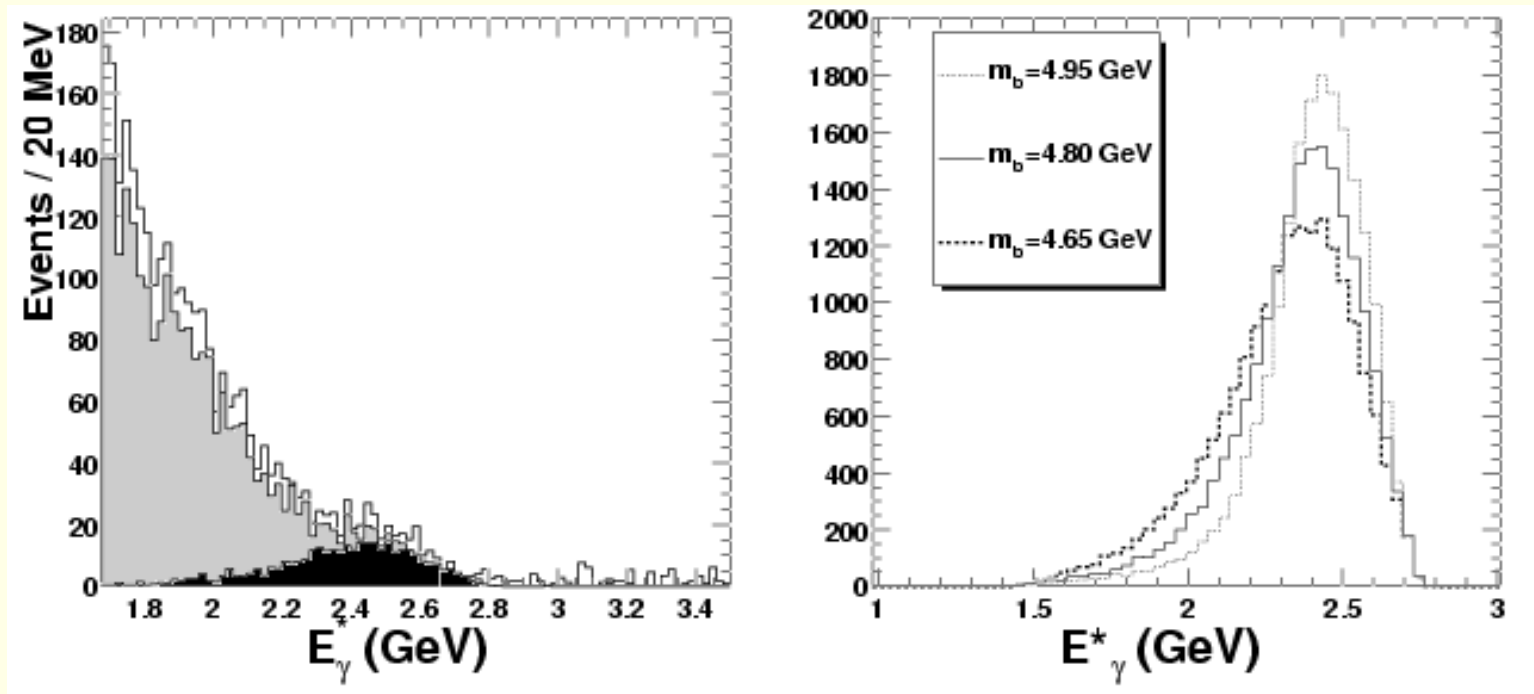


2. Theory issue: lowest order is already one loop so new physics should be prominent

3. Experimental problems: backgrounds, need model to get full spectrum

- To reduce background, require $E_\gamma^* > E_{min}$
- Require lepton from other B to remove continuum; MC to remove $B^0 \bar{B}^0$ bkgd
- Need theory for spectrum, not just total rate
- Theoretical prediction for spectrum above 2.2 GeV uncertain by about 15%

$b \rightarrow s \gamma$ Backgrounds, Extrapolation



Uncertainty in m_c limits precision of extrapolating below 2.1 GeV. BaBar ICHEP presentation, based on Kagan and Neubert.

$b \rightarrow s \gamma$ Theory Issues

- At high energies, ignore QCD [asymptotic freedom]
- QCD corrections plus QED generate effective low energy interactions

$$\mathcal{O}_2 = \bar{s}_L \gamma_\mu c_L \bar{c}_L \gamma^\mu b_L \text{ [ordinary weak interaction]}$$

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} b_R F_{\mu\nu}$$

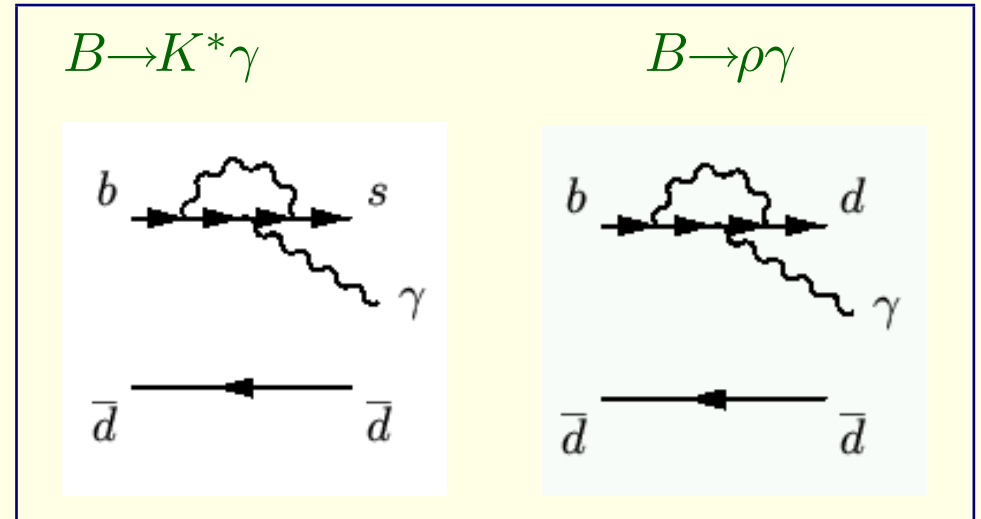
$$\mathcal{O}_8 = \frac{g_s}{16\pi^2} m_b \bar{s}_L \frac{1}{2} \lambda^a \sigma^{\mu\nu} b_R G_{\mu\nu}^a$$

$$\mathcal{H} \propto \sum_j C_j(\mu) \mathcal{O}(\mu)_j$$

$$C_j(m_b) = \sum_k (\text{evolution coef.})_{jk} C_k(m_W)$$

$$B \rightarrow K^* \gamma / B \rightarrow \rho \gamma$$

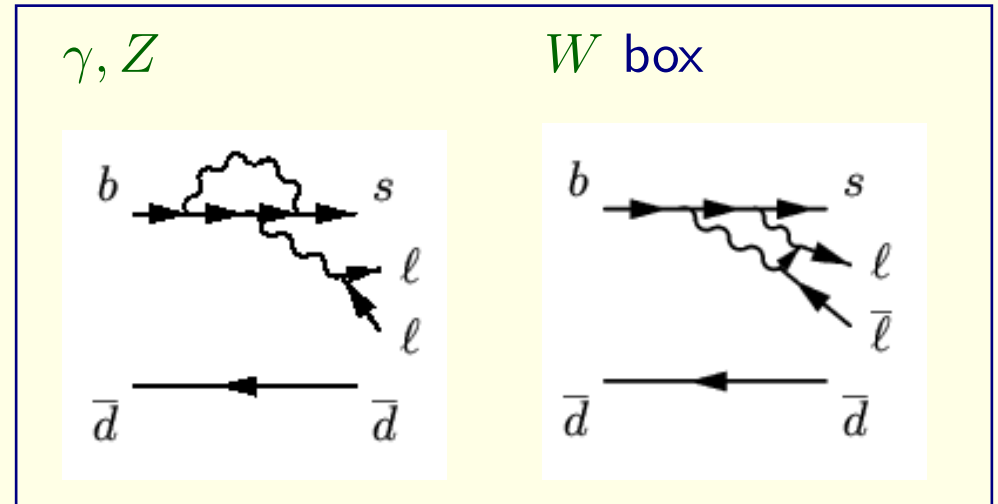
1. Measure exclusive decays
2. Theory issue: non-perturbative matrix element
3. Ratio gives $|V_{ts}/V_{td}|^2$, but with model dependence
4. Experimental: clean for K^* , small rate for ρ



$$b \rightarrow s \ell \bar{\ell}$$

1. Measure exclusive decays and sum, excluding in J/ψ etc.

2. Theory issue: probes γ, Z and W box diagrams



3. Experimental: clean for $K^* \ell \bar{\ell}$

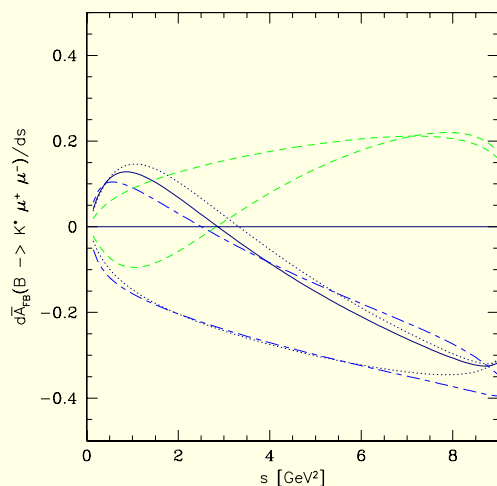
New Operators:

$$\mathcal{O}_9 = \frac{e}{16\pi^2} \bar{s}_L \gamma_\mu b_L \bar{\ell} \gamma^\mu \ell$$

$$\mathcal{O}_{10} = \frac{e}{16\pi^2} \bar{s}_L \gamma_\mu b_L \bar{\ell} \gamma^\mu \gamma_5 \ell$$

$b \rightarrow s \ell \bar{\ell}$ Forward-Backward Asymmetry

- Comes from interference between axial (\mathcal{O}_{10}) and vector ($\mathcal{O}_{7,9}$)
- Need to understand various form factors evaluated at $s = m_{\ell\bar{\ell}}^2$
- New Physics can enter through $\mathcal{C}_{7,9,10}$



Forward-Backward Asymmetry in $B \rightarrow K^* \mu^+ \mu^-$ for SM and some SUSY models,
Ali, et al. PRD 61, 074024
BTeV, SuperB will have 1000's of events

$$K^+ \rightarrow \pi^+ \nu \bar{\nu}$$

1. Measure one charged particle!

2. Theory issue:

$$\mathcal{A} \propto V_{td}, |\mathcal{A}|^2 \propto (1 - \rho)^2 + \eta^2$$

with charm contribution

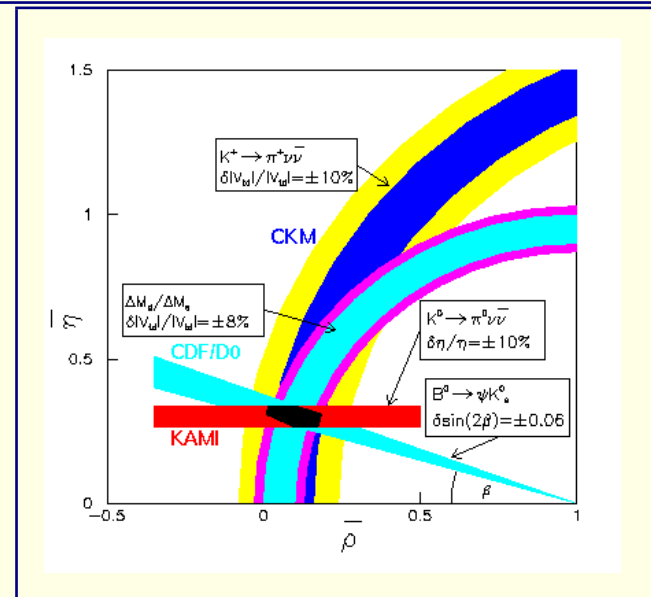
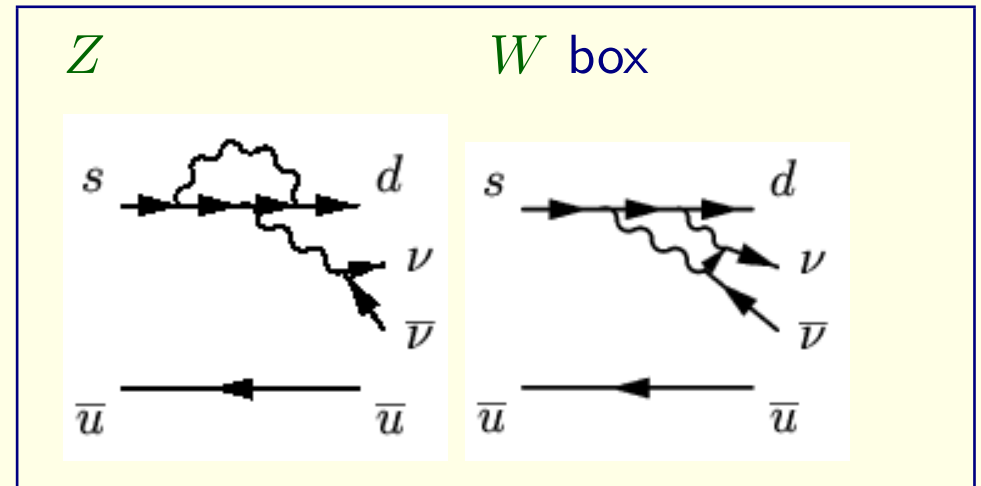
$$\rightarrow |\mathcal{A}|^2 \propto (1.42 - \rho)^2 + \eta^2$$

3. Experimental: very low branching ratio

$$0.77 \pm 0.21 \times 10^{-10} \text{ (th)},$$

$$1.5^{+3.4}_{-1.2} \times 10^{-10} \text{ (exp)}$$

4. CKM aims for 100 events



$$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$$

1. Measure two photons !

2. Theory issue: cleanly measures η

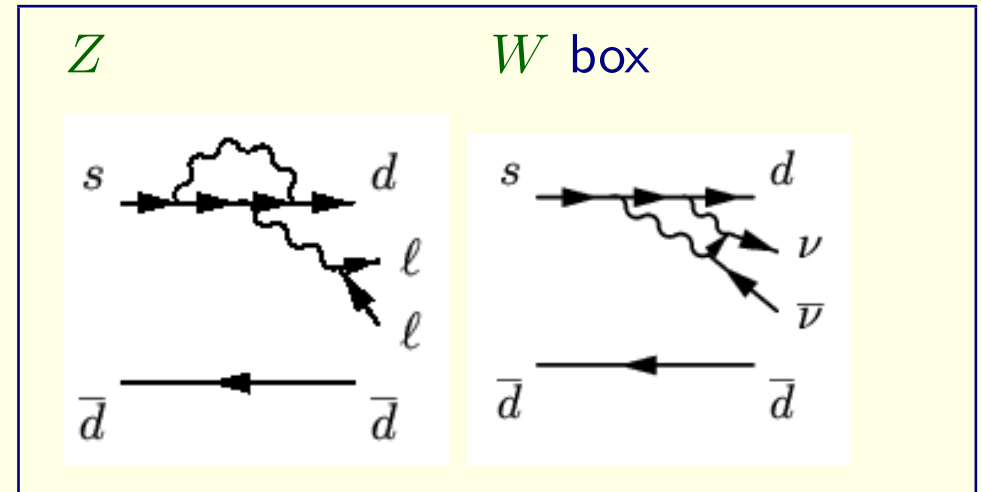
$$|K_L\rangle = [|K^0\rangle - |\bar{K}^0\rangle]$$

$$\mathcal{A} \propto V_{td} - V_{td}^* = \eta$$

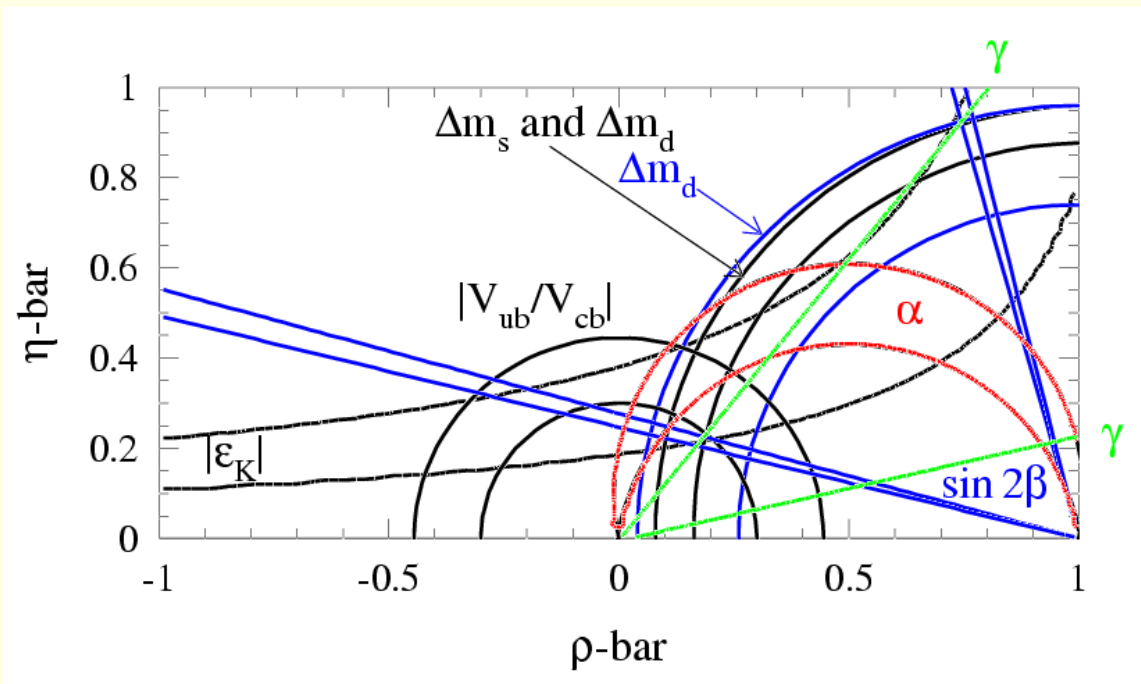
3. Experimental: very tough!!

4. KOPIO - part of RSVP - bunched beam \rightarrow TOF $\rightarrow K_L$ momentum

5. Goal is 10% measurement of η

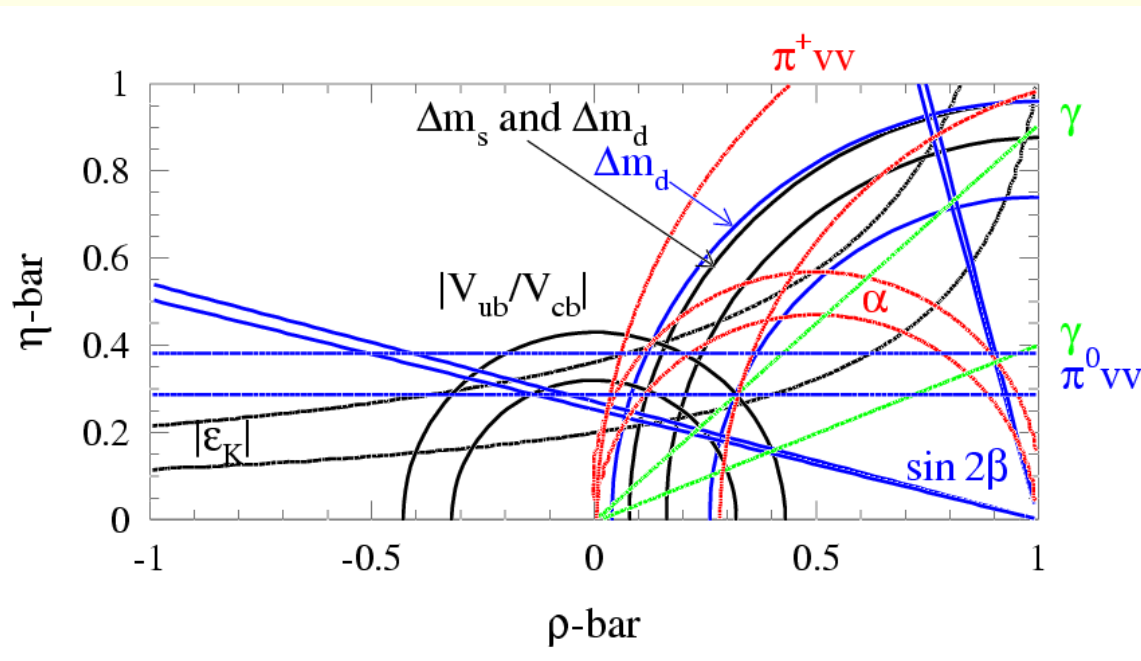


Projection by CKMFitter Team



- $\Delta m_s : \pm 0.2\%$
- $\sin 2\beta : \pm 0.01 \pm 0.01$
- $\alpha : \pm 5^\circ$
- $\gamma : \pm 10^\circ$
- $|V_{ub}| \pm 10\%$

More Ambition Projection by CKMFitter Team



- $\Delta m_s : \pm 0.2\%$
- $\sin 2\beta : \pm 0.007$
- $\alpha : \pm 2^\circ$
- $\gamma : \pm 6^\circ$
- $|V_{ub}| \pm 10\%$
- $\mathcal{B}(K_L \rightarrow \pi^0 \nu \nu) : \pm 7\%$
- $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \nu) : \pm 5\%$

Spirit of Next Generation Flavor Physics

- Standard Model likely to have been verified to basic level:
 - Success of SM in $\sin 2\beta$ impressive
 - Had been likely target for deviation
- Only deviations that are truly convincing are likely to be interesting
 - 2 σ : 50 theory papers
 - 3 σ : 250 theory papers
 - 5 σ : strong sign of effect

Beyond the Standard Model: Now and Then

- Now

- Pick model e.g. Minimal Supersymmetric Standard Model
- Restrict it to reduce free parameters
- Constrain parameters so no egregious violations of current data
 - * EDM
 - * $\epsilon, \epsilon'/\epsilon,$
 - * $\Delta m_d, \sin 2\beta, b \rightarrow s\gamma$
- Predict other observables in B system

- Then

- Pick model consistent with LHC discoveries and exclusions
- Vary parameters, look for observable effects
- Use flavor physics results to constrain models

Summary

- Many channels for K, B_d, B_s decays that have great interest
- Three worthy paths
 - Test QCD-improved electroweak theory
 - Validate Standard Model
 - Look beyond Standard Model
- Some channels that are theoretical and experimentally clean
 - $B \rightarrow J/\psi K_S, B \rightarrow \phi K_S, B_s \rightarrow J/\psi \phi(\eta'), B \rightarrow DK, B_s \rightarrow D_s K, K \rightarrow \pi \nu \bar{\nu}$
- Some require advances in QCD corrections/lattice gauge calculations
- By uncovering new quanta, LHC will raise the bar for flavor physics